

Consultant Report on:

**STAR Panel for Coastwide Bocaccio and Canary
Rockfish**

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1 SUMMARY

The bocaccio and canary rockfish assessments were of good quality and should provide good scientific advice. The consensus view on these assessments is in the STAR Panel Review report. As with any assessment, there are areas of significant uncertainty that should be addressed in future, and this report gives a personal view on these.

Future recruitment simulation will be important in estimating rebuilding times that are used as the basis for setting quotas. Although the methods proposed were acceptable, I believe better general methods based on the smoothed bootstrap and/or ARIMA modelling may lead to more robust and better projections of recruitment.

As the time series of data lengthen, climate change is likely to become more important as a factor in many stock assessments. Historical reference points and projections are vulnerable to long term cycles and trends in recruitment. I believe further research is required on the implication of climate cycles and trends to stock assessments.

In general, the stock assessments were sensitive to estimates of historical catch. I make a suggestion that may provide or improve estimates of species catches where direct observations on species composition or discarding are unavailable.

The assessments were dependent on the triennial trawl fishery, particularly as fishery dependent indices are compounded by management controls. More frequent fishery independent surveys are very desirable. I suggest gears such as longline or gillnets are used rather than trawls to improve selectivity estimates.

The STAT team suggested the bocaccio stock could be separated into two populations. It was agreed by the STAR panel that this could be modelled in future assessments, but a single population model should apply for the moment. I suggest an approach to modelling connected populations that I believe is better than the current approach in the Synthesis software used for the assessment.

2 BACKGROUND AND REVIEW ACTIVITIES

Coastwide stock assessments for canary and bocaccio rockfish were undertaken using the most recent fisheries information. The assessments used Synthesis, which fits a sequential population analysis model using both size and age data. The bocaccio rockfish stock covered both southern and central California, whereas canary rockfish extends from California north across the Canadian border. Both species are mainly caught by trawl and the recreational fishery. They are heavily depleted and now subject to rebuilding programs. The assessment models, once agreed, will be used to simulate

recovery and thereby set maximum quotas through previously defined reference points.

I received preliminary reports at least one week before the review meeting. The meeting was conducted at the auditorium of the Northwest Fisheries Science Centre, Seattle 15-19 April 2002. Some outputs requested during the review as well as the final stock assessment reports were examined after meeting through email. Details of the meeting are given in the STAR Panel Review team's report.

3 COMMENTS ON THE ASSESSMENTS

3.1 General

The following are some personal observations on how the assessments for bocaccio and canary rockfish might be improved in future and are not necessarily shared by the other panel members. This report does not repeat information contained in the STAR panel report that expresses the panel's consensus view, but does address some of the issues in more detail, and makes suggestions on possible approaches to solve them.

As in previous reviews, the assessments were well conducted and the STAT teams were very helpful and open in explaining the assessment and the problems they had with it. In my opinion, reviews are constructive and do produce improved assessments.

In this instance, no analyses were carried out during the review by panel members. The assessments used Synthesis, which is specialised statistical catch-at-age / catch-at-length assessment software. The software was clearly very powerful, but was constructed over a long period, so that it contained many idiosyncrasies and was not easy to use. Fortunately, Richard Methot, the author of the software, was present to run it, which helped the review a great deal¹.

I am concerned that there is a tendency to overfit data. This tends to lead to models that are difficult to fit and may produce unreliable individual parameter estimates. I could not detect any particular problem in these assessments, and compared to AD modeller assessments I have seen, they were parsimonious. Nevertheless, they are non-linear models with over 100 parameters, which makes them very complex.

There was a noticeable improvement in the data available since I last attended a STAR panel review (widow rockfish and lingcod, June 5-9, 2000). Most importantly the assessments included, as far as possible, both recreational and Canadian catches. Absence of these sources of data would have made any decision based on these assessments less sound. The STAT

¹ I have requested a copy of Synthesis so that I can become more familiar with it.

teams and others should be commended in the way methods and data are being continuously improved.

At least some of the panel review was concerned with details of the data set used. I have no experience with these data sets, so was unable to make a useful contribution in this area. However, it does seem strange that the STAT teams are left to make the best guess on how to estimate total catches and other data from the databases. I would have thought the best people to estimate these quantities would be the statisticians responsible for the data collection programs. Estimation of common quantities, such as total catch by species and year should ideally be implemented as queries in the databases. As the same issues apply to several species at once (e.g. early trawl catches of rockfish), these could all be dealt with as a single issue, rather than revisiting the same problem at each single species assessment.

While a minimum size for the STAR panel is specified, the STAT teams are not so fortunate. I would suggest the STAT team should consist of at least 2 people so that requested work could be realistically completed within the week. In the bocaccio case, a new model was required, with all its associated diagnostics. Considering the time constraints, this was not possible for one person to achieve during the review meeting.

The final result in all cases is that the biomass for both canary and bocaccio rockfish has dramatically declined. This was confirmed by all indices, so there is little doubt over the state of these stocks. However, the projections of the stock recovery was considerably less certain. Such long-term projections over many years cannot hope to be accurate, particularly as no recovery has yet been observed. Once recovery (an increasing trend in the abundance indices) has been observed, the estimated rebuilding time will become much more certain. This would underline the need for more frequent fisheries independent surveys. For example, confirming a trend with the triennial survey would probably take a minimum of 15 years.

3.2 Future Recruitment Simulation

The panel decided to support STAT teams in the parametric bootstrap proposal for the canary recruitment projection. The residuals from the stock-recruitment curve would be drawn at random from a lognormal with $\mu=0$ and σ^2 estimated from the observed residuals. Some reservations were expressed, however, with using the log-normal, which may overestimate the frequency of very high recruitments. While it was shown that the residuals were consistent with the lognormal, it is not possible to guarantee that the log-normal will not overestimate the rebuilding time.

The second issue raised was the autocorrelation between residuals. Drawing them from the lognormal would assume they were independent. Autocorrelation will increase the variability in the rebuilding time without increasing the variability in individual recruitments. The autocorrelation of the recruitment log-residuals was in the region of 0.25 and was probably not statistically significant. However, an autocorrelation of around 0.25 could affect the rebuilding time reference points, as they are based on probabilities.

A scheme for non-parametric bootstrap could be developed to account for these two problems. Firstly, a smoothed bootstrap could be used, where residuals are sampled with replacement in the normal way, but the residuals are used as the mean for another smoothing kernel from which a random residual is drawn. This allows the bootstrap values to gather around actual observed residuals but not remain exactly the same in redraws. This should allow more realistic simulations and be more robust than assuming a particular parametric distribution. More complex schemes might be used to ensure the tails of the distribution are adequately modelled (see Silverman 1986).

Constructing a sampling regime with the appropriate autocorrelation is more difficult using a non-parametric method. One option could be to choose values at random, but increase the chance that the next value in the sequence is chosen. This would tend to reproduce the same sequential runs in the time series as that observed in the data, but it would not be possible to raise the autocorrelation to the observed level this way. The only way this could be ensured would be to apply some transform to the bootstrap variables so that they are conditioned on the previous observation in the sequence.

Probably a better and easier method is to include an additional Box-Jenkins ARIMA model within the main population model for estimating the recruitments. The ARIMA model could either be fitted to the residuals as part of the overall fit or separately. This would practically guarantee removal of autocorrelations from the SR residuals. The ARIMA residuals can be used in the bootstrap. The full time series of residuals can then be used to reassemble the set of recruitments by using the ARIMA model to get the SR residuals, then add these residuals to whichever SR model is being used. ARIMA models are particularly useful because they can reintroduce trends in residuals as well as autocorrelation. This gives a genuine pattern to residuals which otherwise can look idealised.

3.3 Climate Change

As the time series of catches is extended, long term affects such as climatic change may become more important. This may be particularly important where the initial biomass is being used as an estimate of the unexploited biomass reference point. I think there is a strong case for considering the potential impact of climate on stocks.

Klyashtorin (2001) argued that fluctuations in many of the world's fish stocks could be attributed to climatic cycles. If this is so, assessment methods that assume some equilibrium in the past may be biased. Any policy which aims at fixed catch quotas would be likely to recommend fishing at unsustainable levels at some point during the cycle.

I think the climatic effect has not been proved for many of the fisheries considered by Klyashtorin (2001) since the index changes have coincided with development of gear and technology. Recovery is also quite likely to occur in the predicted fashion as rebuilding programmes begin to have an effect, although climate would probably have an effect. However, production

for some stocks is expected to decline over the next 25 years, and these may provide some sort of test.

There is a justification for including climate effects in sensitivity runs, even if climate is not included in the base model. It is most likely that climate affects recruitment, so strong year classes may be delayed until the climate cycles through another half revolution (Figure 1). This would counter some of the more pessimistic predictions for rockfish stock recovery, although trends in climate change, such as global warming, may make any long term prediction uncertain.

The climate issue is probably more important for setting quotas in the future to avoid another stock collapse. Given that the issue is not urgent, I would recommend further research is undertaken on how climate effects might be meaningfully incorporated in stock assessments rather than model artificial recruitment cycles.

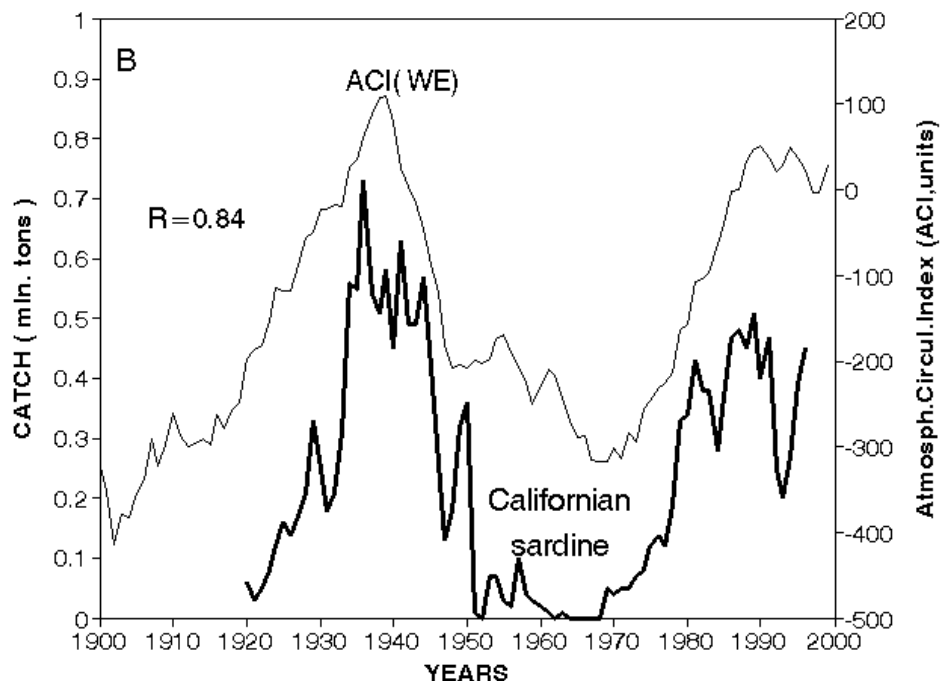


Figure 1 Correlation between Atmospheric Circulation Index (ACI) and catch of California sardine (from Klyashtorin, 2001). The declines in both canary and bocaccio rockfish coincide with the increasing ACI.

3.4 Historical Catches

The assessments were sensitive to the estimates of historical catches. While the total rockfish catch is probably recorded with good accuracy, there was considerable uncertainty over allocation among species and amount discarded. These issues will be solved for the current data by implementation

of the on-board observer program. However, this will not solve the historical data problem, and some improved way of extrapolating estimates back in time would be valuable.

The method used to estimate historical species catch or discard was a fixed proportion of the total catch extrapolated over years where no information was available. I suggest an alternative approach that may be more accurate as it makes use of all species information simultaneously.

Most species groups occur in one of a few abundance patterns. Species abundance models, such as the log-normal, log-series and broken stick models, are used to describe these patterns (see Magurran 1988). Under many circumstances species abundance models can be used to estimate abundance with greater accuracy than estimating the abundance of each single species alone.

The species abundance model most likely applicable to rockfish would be the log-normal which has two parameters. The log-normal abundance model has been found to fit the widest variety of ecological communities (Magurran 1988). Most of these models are justified on the division of niche space (May 1975, Sugihara 1980), but agreement is not universal, particularly over the application of the lognormal (Ugland & Gray 1982). Nevertheless, the pattern may apply, even if the reason for it is unknown. The least selective gears are trawls, which have been shown in one case at least to be log-normal (Magurran and Abdulquadar, unpubl. data cited in Magurran 1988).

Given the model parameter values together with the rank of the species in the abundance order and the number of species in the community, an estimate of the species abundance can be obtained. Parameter estimates can be obtained from fitting the model to data where the full species composition is known. As the total abundance of all species is one of the model parameters, estimates of the abundance of individual species can be obtained from total catches as long as the second model parameter (sigma) and species rank do not change. This would probably hold as long as the extrapolation was not too far from the observations.

The same approach applies estimating discards. If it is known that there are 60 species caught, but only 40 appear in the landings, then the quantity discarded can be estimated from the abundance model.

There are two problems with the approach:

- The species rank may change over time, which is quite possible due to fishing activities and climate change. The same problem would also arise with using a fixed proportion of the catches. Where the abundance rank is not known for certain, it is possible to integrate the likelihood over the possible ranks². This is likely to be the case in most applications, but significantly decreases the accuracy of the estimate.

² I have software to do this which I can provide on request.

Because the estimated quantity is the logarithm of the catch, the final estimate will have low precision.

- The composition may not only be by species, but also by size (e.g. discarded small versus large rockfish). In my experience, the log-normal appears robust to this error. As long as the abundance model is fitted to the classes as required, it can be confirmed whether or not the log-normal is appropriate.

3.5 Set-Gear Surveys

A consistent problem for the west coast fisheries is the reliance on the triennial trawl surveys. While these are valuable, they are two infrequent considering the reliance placed on them as abundance indices. They also have a significant problem with uncertainty over their selectivity, which has led to prolonged discussions at the two STAR panel meetings I have attended. The problem with using trawl gear is its inability to survey all areas, so if the proportion of the stock (by age or sex) in inaccessible areas varies with stock abundance, abundance indices and age or size composition may be poor.

Passive gears, notably gillnets and longlines, can not only survey areas not accessible to trawl gear, but also have well-defined selectivity patterns (e.g. Hovgård and Lassen, in print). The survey design and various capture models can relate survey catches to more accurate estimates of abundance and the abundance error. The selectivity parameters might be estimated within the survey design, thereby reducing reliance on estimating these parameters with sequential population analysis models. I believe this might make the assessments more reliable. They can be more flexible also in allowing adaptive sampling (which allows clustering of the sampling pattern to areas of high density).

As an alternative to increasing the triennial trawl survey effort, either longline or gillnet surveys could be used. It may take a few survey years before these data would become useful, although estimates on absolute abundance may be possible from well-designed surveys.

3.6 Migration Model for Two Populations

It was suggested during the meeting that a two-population model for bocaccio would be appropriate. I agree that such models may describe reality better than assuming either a single homogeneous population or two entirely separate populations. Each extreme may be a reasonable approximation to either large migration or relatively isolated populations.

If I understand it correctly, Synthesis allows fixed proportional migration for each age group as a discrete movement once each year. This I believe is a poor way to model movement. Because it does not allow continuous movement through the year, the estimates of fishing mortality can be greatly distorted. It seems unreasonable to spend considerable computations on estimating accurate F 's in other respects while using an inaccurate

approximation for migration, which can have a large impact on the behaviour of the model. The migration model was not used in these assessments.

I would propose treating migration in the same way as natural mortality, as an instantaneous rate parameter (see Appendix III). As for natural mortality, it will probably be difficult to estimate without direct observations, such as from tagging experiments. However, it can still be parameterized and the sensitivity of the results tested against different levels of connectivity between regions. For example, the same model could be used to test both zero, intermediate and high levels of migration between north and central California areas to see which provides the best fit to the bocaccio data.

4 RECOMMENDATIONS

- Further research should be conducted on including climate cycles and trends in stock assessments.
- Improved methods for simulating recruitments, such as the smoothed bootstrap and Box-Jenkins ARIMA models, should be considered for future assessments.
- Historical catches should be estimated for all species simultaneously, perhaps using an ecological abundance model. This should be undertaken by those closest to the data collection program and provided to the stock assessment scientist, ideally with standard errors.
- More frequent fishery independent surveys should be undertaken, perhaps using gears such as longline or gillnets to improve selectivity estimates.
- The future assessment model for Bocaccio should have two populations, one each for southern and central California. I recommend the migration be modelled as an instantaneous rate rather than discrete annual movement to avoid bias on the F estimates which may vary among areas.

5 REFERENCES

- Hovgård H, Lassen H. (in print) Estimation of selectivity for gill net and longline gears in abundance surveys. Fisheries Technical Paper. FAO Rome.
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- Silverman, B.W. 1986. Density estimation for statistics and data analysis. Chapman and Hall, London. 153p.
- Sugihara G (1980) Minimal community structure: an explanation of species abundance patterns. Amer. Nat. 116: 770-787
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6 ATTENDANCE

STAR Panel Members

Gary Stauffer chairman, NMFS, AFSC, Seattle, WA

Tom Ghio, GAP representative

Larry Jacobson Rapporteur (canary), NMFS, NEFSC, Woods Hole, MA

Paul Medley Rapporteur (bocaccio), Center for Independent Experts, Miami University, FL

Stephen Ralston Rapporteur (canary), SSC representative, NMFS, SWFSC, Santa Cruz

Mark Saelens GMT representative, Oregon Department of Fish and Wildlife, Newport, OR

Canary Rockfish Team

Keven Piner, NMFS, AFSC, Seattle, WA

Richard Methot, NMFS, AFSC, Seattle, WA

Bocaccio Rockfish Team

Alec MacCall, NMFS, Southwest Fisheries Science Center, CA

APPENDIX I: STATEMENT OF WORK

Consulting Agreement Between The University of Miami and Dr. Paul Medley

June 7, 2002

General

The consultant will participate in the Stock Assessment and Review (STAR) Panel of the Pacific Fishery Management Council (PFMC) from April 15-19, 2002. The STAR panel will review the Canary rockfish and Bocaccio stock assessments. This assessment will provide the basis for management of the Bocaccio and Canary rockfish. These two species have been declared overfished.

The consultant's duties shall not exceed a maximum total of 14 days: Several days prior to the meeting for document review; the five-day meeting; and several days following the meeting to complete the written report. The report is to be based on the consultant's findings, and no consensus report shall be accepted.

The consultant will be provided with the most recent Bocaccio, and Canary rockfish assessment reports and electronic copies of the data, parameters, and model used for the assessments (if requested).

Specific

- 1) Become familiar with the current Bocaccio, and Canary rockfish stock assessments;
- 2) Understand the primary sources of uncertainty in the assessments;
- 3) Comment on the strengths and weaknesses of current approaches;
- 4) Recommend alternative model configurations or formulations as appropriate during the STAR panel;
- 5) No later than May 3, 2002, submitting the written report³ addressed to the "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via email to ddie@rsmas.miami.edu.

Signed_____

Date_____

³ The written report will undergo an internal CIE review before it is considered final. After completion, the CIE will create a PDF version of the written report that will be submitted to NMFS and the consultant.

APPENDIX II: REVIEW DOCUMENTS

Status of the Canary Rockfish Resource off California, Oregon and Washington in 2001 by Richard Methot and Kevin Piner, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Wa Draft version for review.

Status of the Canary Rockfish Resource off California, Oregon and Washington in 2001 by Richard Methot and Kevin Piner, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Wa 26 April 2001.

Status Of Bocaccio Off Central And Southern California In 2002 by Alec D. MacCall, Santa Cruz Laboratory, Southwest Fisheries Science Center, Santa Cruz, CA Review Draft 1.0 (Results are preliminary)

Status Of Bocaccio Off Central And Southern California In 2002 by Alec D. MacCall, Santa Cruz Laboratory, Southwest Fisheries Science Center, Santa Cruz, CA Final version executive summary.

The final Bocaccio report should arrive by 7 May 2002.

APPENDIX III: SPATIAL POPULATION MODEL FOR BOCACCIO

6.1 A Migration Model

The simplest movement extension to stock assessment models is to include emigration and immigration as constant rates between a fixed number of discrete populations. The immigration-emigration rates work in exactly the same way as natural mortality, except fish are not lost to the populations, they move between them. The advantage of having fixed rates in this form is that a mathematical solution to the dynamics model is available. This represents an extension applicable to most stock assessment models which include a term for survival or mortality.

Populations are treated as discrete units with parameters. The net change in population size is due to new arrivals from other populations versus emigration.

$$\frac{dN_i}{dt} = \sum_j \alpha_{ji} N_j - N_i \left(\sum_j \alpha_{ij} + F_i + M \right) \quad i \neq j \quad (1)$$

If there are n populations, there will be n linear differential equations describing the system. Rates α_{ij} are assumed to be constant, so Equation (1) is simply the negative exponential population model extended to an arbitrary number of discrete populations.

Equation (1) can be written in matrix form by separating the rate parameters into a matrix (**A**) and population sizes into a vector (**N_t**). The negative right hand term in equation (1) forms the diagonal (trace) of the matrix.

$$\mathbf{A} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \cdots \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \cdots \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \quad (2)$$

The trace of the matrix contains not only the rate of departure, but also all mortality. The solution to this set of ordinary differential equations is given by the exponent of the matrix:

$$\mathbf{N}_t = e^{\mathbf{A}t} \mathbf{N}_0 \quad (3)$$

The transition matrix is calculated as:

$$e^{\mathbf{A}t} = \mathbf{I} + \mathbf{A} + \frac{\mathbf{A}^2}{2!} t^2 + \frac{\mathbf{A}^3}{3!} t^3 + \cdots \quad (4)$$

\mathbf{I} being the unit matrix. The solution can be made to converge very rapidly, particularly for small matrices⁴.

While there is relatively simple mathematical solution, the number of parameters can become very large with only a few populations. In practice, fitting these parameters will be impossible except under controlled experimental conditions.

For the two population case, the matrix \mathbf{A} would be:

$$\mathbf{A} = \begin{bmatrix} -(\alpha_s + F_s + M) & \alpha_c \\ \alpha_s & -(\alpha_c + F_c + M) \end{bmatrix} \quad (5)$$

where α_s and α_c is the emmigration rate and F_s and F_c the fishing mortality for southern and central California respectively.

The simplest approach would be to fit F 's to the catch matrix using an Adapt-type method. This would involve calculating the matrix exponent for each age class, then the expected catches. Catches can be calculated using the matrix version of the catch equation:

$$\mathbf{C}_a = \mathbf{F}\mathbf{A}^{-1}\mathbf{N}_a(\mathbf{I} - \mathbf{e}^{\mathbf{A}}) \quad (6)$$

where \mathbf{F} is a matrix of the F 's (along the matrix diagonal). C_a is the catch and N_a is the population at age a . The catch equation can be solved using Newton's method. A simpler way is to use the cohort analysis approximation:

$$N_{a+1} = N_a e^{A_M} - C_a e^{A_M/2} \quad (7)$$

where \mathbf{A}_M is the rate matrix excluding the F 's. Obtaining the F 's involves inverting and taking natural logarithms of a matrix of the population proportions. The matrix to be logged is the proportion of the initial population size in a matrix where the numbers migrating is explicit. The matrix logarithm can be obtained from the appropriate Taylor expansion used for the exponent, but may be slow to converge as it is a power series:

$$\ln(\mathbf{P}) = (\mathbf{P} - \mathbf{I}) - \frac{(\mathbf{P} - \mathbf{I})^2}{2} + \frac{(\mathbf{P} - \mathbf{I})^3}{3} - \dots \quad (8)$$

where \mathbf{I} = identity matrix

$$\mathbf{P} = \begin{bmatrix} \alpha_{11} N_{sa+1}/N_{sa} & \alpha_{12} N_{ca+1}/N_{ca} \\ \alpha_{21} N_{sa+1}/N_{sa} & \alpha_{22} N_{ca+1}/N_{ca} \end{bmatrix}$$

Unfortunately this approximation seems very poor, although it may give a start point for the F 's. It probably could be improved, but with the log-transform, it may be just as quick to solve for the F 's directly. However, it is worth emphasising that inaccurate F 's estimated from this method are still probably

⁴ The relevant visual basic routines are available on request.

more accurate than the fishing mortalities from a model using a single annual discrete movement.

6.2 Example: Estimating exchange between populations

In this very simple simulated example there are two populations with a recruitment index for each. To describe the migration dynamics we need no more than one parameter per population as emigration is reciprocal. However, the initial unexploited stock sizes cannot be used as these would be determined as much by unknown historical levels of recruitment as by migration. The simulated data consist of 15 year time series of recruitment index, catch and effort broken down between two fishing grounds.

Four scenarios were simulated:

- There is no exchange ($a_1 = 0$, $a_2 = 0$), so the populations are independent ($\pi = 0$),
- There is some medium rate of migration between them ($a_1 = 0.4$, $a_2 = 0.4$) so the populations are connected, but different ($0 < \pi < \infty$),
- The exchange is very high ($a_1 = 20$, $a_2 = 20$) so the populations are essentially a single population,
- There is a net movement from one population to the other ($a_1 = 0.4$, $a_2 = 0$).

Likewise, there are three choices of model to fit. The data can be combined assuming a single population, the analyses can be kept entirely separate, or the fixed migration model can be fitted. Note that the migration model can be effectively parameterised to represent all three cases and was used to simulate the data. By fitting the model, we can see how well each of the approaches to estimation behave.

In general, the single model combining catches and recruitment indices fits all CPUE series well, regardless of the degree of migration (Table 1). Separate models do generally worse mainly because they require more parameters. However, where there is genuine transfer of fish in one direction between populations the separate population does fit significantly better. The migration model fits better under all circumstances, but it is assumed the migration parameters are known exactly. The migration model fits best when the migration rates are unbalanced so there is net movement of the population. However, using only the apparent goodness-of-fit (measuring the correlation between the observed and expected CPUE) it is unlikely any particular approach would be clearly better. The most robust approach would probably be to consider the implications of the different migration hypotheses based on the fitted migration model.

Table 1 Results from simulating data from two populations subject to different rates of exchange. Three estimation models were used, a single population model, two separate models and two separate models including migration. The R^2 values indicate the apparent goodness-of-fit, the root mean squared error (MSE) the relative real goodness-of-fit. There is no clear pattern, and the suggestion is it will not be possible to identify net movements from simple catch and effort data. Combining data outperforms separate analyses with the exception where there is net movement from one population to the other.

		$a_1 = 0, a_2 = 0$	$A_1 = 0.4, a_2 = 0.4$	$a_1 = 20, a_2 = 20$	$a_1 = 0.4, a_2 = 0$
Single	R^2	0.928	0.952	0.952	0.927
	MSE	182086	297017	365087	725755
Separate	R^2 1	0.633	0.806	0.815	0.828
	R^2 2	0.985	0.848	0.678	0.818
	MSE	916084	835789	860674	375070
Migration	R^2 1	0.749	0.810	0.761	0.937
	R^2 2	0.982	0.943	0.909	0.924
	MSE	306786	214176	173864	171749

On testing whether it is possible to fit the migration parameters, some success was obtained when all other parameters were fixed at their true values (Table 2). While the model was able to discriminate between different levels of migration and unbalanced rates between the populations, estimates were not accurate. It is not realistic to estimate these parameters alongside other parameters such as spatially varying catchability, as apart from the general inaccuracy, they are hopelessly aliased.

Table 2 Estimated rate of exchange when all parameters apart from migration rates are known. While parameter estimates do reflect general underlying patterns, the estimates do not appear accurate.

a_1		a_2	
Estimate	True	Estimate	True
0.038	0	0.165	0
0.901	0.4	0.662	0.4
3.810	20	3.220	20
0.604	0.4	0.068	0

Probably, without external information such as tagging or relative length frequencies, there is about as much chance of fitting emigration rates as there is of fitting the natural mortality parameter, i.e. very little. These parameters are too heavily correlated with other parameters in the models. However, the model can still be used to see whether the data supports spatial disaggregation, rather than estimating movement *per se*.

If areas are classified for testing differences in catchability, it may be worth seeing whether differences may also have implications for the population

dynamics. This can be done either by attempting to fit migration models or use them in simulations to see what affect population movement may have on the estimates and decisions.